TYPHLODROMUS MCGREGORI CHANT (ACARINA: PHYTOSEIIDAE) AND ITS CONTROL OF PHYTOPHAGOUS MITES IN UTAH AND SOUTHERN CALIFORNIA APPLE ORCHARDS[1]

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Abstract.—A review of published and unpublished data for the predatory mite *Typhlodromus mcgregori* in Utah and southern California apple growing areas is presented to summarize its role. *Typhlodromus mcgregori* was not found resistant to pesticides and, although usually present with *Bryobia rubrioculus*, only when *Aculus schlechtendali* was also present was there significant predation on *B. rubrioculus*. *Aculus schlechtendali* was considered the primary host and *B. rubrioculus* secondary for *T. mcgregori*. *Typhlodromus occidentalis* was always found associated with *Tetranychus* spp. and often with *Eotetranychus* and *Pronematus ubiquitus* in unsprayed orchards.

Certain phytoseiid mites are specialized predators of phytophagous mites and are capable of controlling or suppressing their populations at low densities (Collyer 1964, Hoyt 1969, Croft and Barnes 1971). This potential for biological control has prompted studies of the native species in many agricultural areas of the world (Huffaker et al. 1969), and, although predator-prey relationships vary in different geographic regions, similar associations are not uncommon in areas where ecological conditions are similar.

During 1967-70, Jorgensen and co-workers (Jorgensen 1968, Nelson and Jorgensen 1968, Croft and Jorgensen 1969, Leetham and Jorgensen 1971, and Duke et al. 1970) investigated predator-phytophagous mite relationships in Utah apple orchards. They reported *Typhlodromus mcgregori* Chant and *T. occidentalis* Nesbitt in predatory association with *Bryobia rubrioculus* Scheuten and *Tetranychus mcdanieli* McGregor, respectively.

Croft (1970) found predator-prey relationships in mountain apple orchards of southern California (Oak Glen, near Yucaipa, Calif.) almost identical to those reported in Utah. Because of this and similar native vegetation, he concluded that the Oak Glen environment was an extension of the ecological type reported for Utah, and atypical of other apple areas in California. His conclusions were also influenced by the common occurrence of *Tet. mcdanieli* throughout Utah and at Oak Glen. This species is not reported from other apple areas of California (Barnes and Madsen 1961). These similarities allow for the summary of both areas in this single analysis and should provide a general understanding of the role occupied by *T. mcgregori*.

Although different techniques were used, both Jorgensen's group and Croft studied the ecology, bionomics, and control effectiveness of *T. mcgregori*. This paper presents additional data and a summary of the predator-prey relationships, along with the apparent role of *T. mcgregori* in both areas. Although *T. occidentalis* was an effective natural enemy of *Tet. mcdanieli* in both regions, references to this predator are limited to comparisons of predator effectiveness or possible niche overlaps with *T. mcgregori* and their respective relationships to the total ecology of mites in the orchards studied.

General Methods

Investigations in southern California were conducted at Oak Glen, an apple growing area *ca* 12.9 km north of Yucaipa, California, at the eastern edge of the Los Angeles basin, and included about 162 ha of com-

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mercial apples grown between 1341-1463 m in the San Bernardino Mountains. Predominant apple varieties in both areas include Delicious, Rome Beauty, and Jonathan. Vegetation types in the southern California study area were typical of those in valleys of more northern latitudes in Utah, i.e., *Acer negundo*, *Prunus virginiana*, *Pinus ponderosa*, and *Symphorocarpus albus*.

Studies on the effects of pesticide treatments on, and the biologies of, certain pest species had previously been conducted in the Oak Glen orchards (Barnes and Madsen 1961). During the summers of 1968-70, sampling studies emphasizing both pedator and prey mite relationships were made. Seven unsprayed, neglected orchards and 11 sprayed orchards, all of the Delicious variety, were sampled at two-week intervals from 13 June to 24 Oct 1968. Spur samples (50 spurs/tree) with leaves were processed using Berlese extraction methods and mites mounted for identification.

During the summers of 1969 and 1970 a series of orchards, including one which had not been sprayed for 10 years, three which had not been sprayed for 3-5 years, and one under a commercial chemical control program, were sampled at two-week intervals to determine population trends of both pest and predatory mites. In samples from five orchards, 20 leaves were collected from five locations of the four compass zones in each of five trees (80 leaves/tree) during the summer. All population counts were made by direct observation through a binocular microscope or from plates of the mite-brushing machine.

In addition to the field studies in California, evaluations of the oviposition rates and developmental times for *T. mcgregori* from egg to adult, when reared on several eriophyid rust mite species, were made in the laboratory. Oviposition rates/female predator for an eight-day period (replicated 10 times ea) when confined on excised apple, peach, or pear leaves containing populations of *Aculus schlechtendali* (Nalepa), *A. coronutus* (Banks), or *Eriophyes pyri* (Pgst.), respectively, at densities of ca 200 rust mites per leaf were determined. Developmental rates for *T. mcgregori*, using four replications with 10 females/replicated leaf when feeding only on *A. schlechtendali* at densities of 200/leaf, were also measured. In all experiments the temperatures were24 ± 2 C and the RH 30-60 percent.

In Utah, two types of studies were conducted. First, an extensive examination of mite distributions and species associations was made (Jorgensen 1968, Nelson and Jorgensen 1968, Leatham and Jorgensen 1971, Duke et al. 1970); however these were only correlative comparisons, and no experiments were done to measure specific associations between the various predator and prey mite populations. Attention was not given to the possibility that rust mites were preferred by *T. mcgregori*. Second, the life history of *T. mcgregori* was studied by Croft and Jorgensen (1969), using *B. rubrioculus*, *Tet. mcdanieli*, and *Panonychus ulmi* Koch as experimental food bases. Again, rust mites were not used as food in these experiments.

Results and Discussion

Mite Fauna at Oak Glen

Mite species collected commonly from unsprayed Oak Glen apple orchards were: Tetranychidae—*Tet. mcdanieli*. *B. rubri*oculus, and *Eotetranychus uncatus* Garman; Phytoseiidae— *T. mcgregori*, *T. occidentalis*, and *T. pomi* (Parrott); and Tydeidae— *Pronematus ubiquitus* (McGregor); Eriophyidae— *A. schlechtendali*; and Erythraeidae— *Belaustium* sp. *Tetranychus mcdanieli* was collected predominantly from commercial orchards which were intensively sprayed with pesticides. Barnes and Madsen (1961) noted the absence of *P. ulmi* from Oak Glen, an observation that was supported during our work.

Unsprayed for Ten Years.— Population levels of phytophagous and predatory mites were extremely variable among trees in this orchard during 1969 and 1970, and for this reason separate plots for two different tree groupings are reported. In three trees during 1969 (Fig. 1A), *B. rubrioculus* attained high population levels of *ca* 40/leaf while only very low populations of *T. mcgregori* developed in late season. In 1970, mites in these same trees showed similar population trends for these two species; however, brown mites only increased to *ca* 15/leaf while *T. mcgregori* was more abundant and reached 0.8/leaf in August (Fig. 1B).

During 1969 (Fig. 1C) and 1970 (Fig. 1D), in two other trees in this orchard, populations of *A. schlechtendali* were present in addition to *B. rubrioculus* and *T. mcgregori*. In these instances, *B. rubrioculus* attained lower peak levels and *T. mcgregori* exhibited a more marked numerical response as compared with the situation when *A. schlechtendali* was not present (i.e., compare data of 1A and B with 1C and D). Although *Tet. mcdanieli* was occasionally found in unsprayed blocks, it was not collected in this orchard, nor was *T. occidentalis*.

Unsprayed from Three to Five Years.— Figures 2A and 2B show the mean densities of *Tet. mcdanieli-Eotetranychus uncatus* (collectively referred to as *Tet. mcdanieli* in Figures 2A and 2B because *E. uncatus* was only present at low densities) and *B. rubrioculus* populations in two apple orchards for the 1969 season. These species were separated temporally; *B. rubrioculus*, with an early season distribution, reached its peak density in July, whereas the *Tet. mcdanieli-E. uncatus* populations began to increase in July and peaked in late August or early

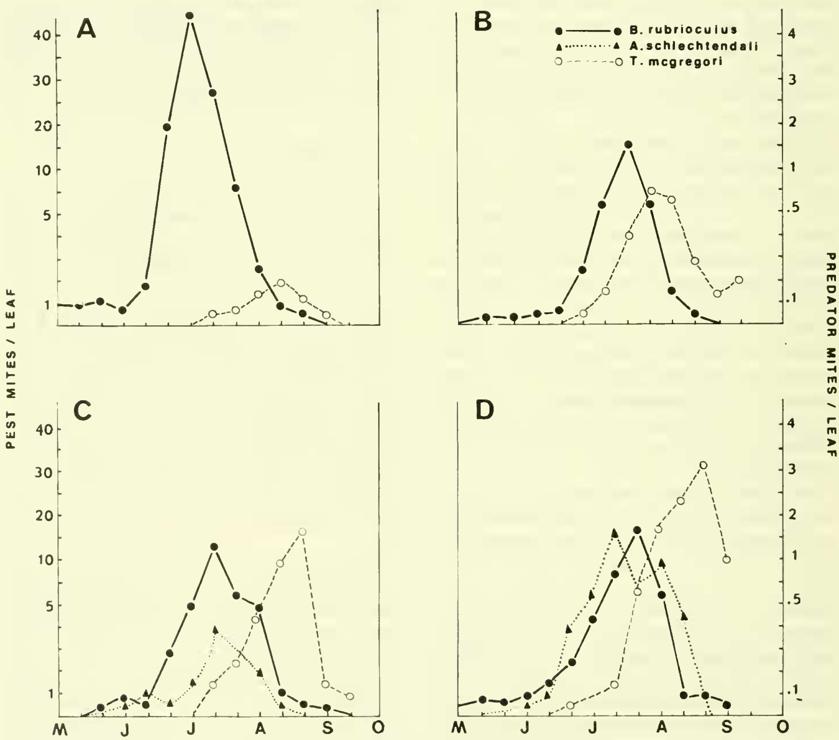

Fig. 1. Densities of plant-feeding and predaceous mites in an apple orchard unsprayed for 10 years at Oak Glen, California: pooled values for three trees during the 1969 (A) and 1970 seasons (B); pooled values for two other trees during the 1969 (C) and 1970 (D) season.

September. The apple rust mite, *A. schlechtendali*, was present in the trees, but almost at undetectable levels. Although both *T. mcgregori* and *T. occidentalis* occurred in these orchards, *T. mcgregori* did not respond markedly to increasing densities of any tetranychid species, whereas *T. occidentalis* populations appeared to increase with increases in the densities of *Tet. mcdanieli-E. uncatus* populations and eventually overcame their populations before they exceeded three to five mites per leaf.

In the other orchard unsprayed for three to five years, *B. rubrioculus* occurred only at very low densities (2 mites/leaf) and *T. mcgregori* was seldom found (Fig. 2C). Rust mites were only occasionally observed in this block (not plotted in Fig. 2C). In Figure 2C the tetranychid mites, *Tet. mcdanieli* and *E. uncatus* began increasing in late July and early August, with an apparent numerical response by *T. occidentalis*. Predator populations increased to nearly 3/leaf before declining to a lower density as prey became scarce. The tydeid, *P. ubiquitus*, increased to a density of 0.6/leaf during the period when the populations of tetranychids were greatest. The presence of both tetranychids and tydeids appeared to provide prey for the observed numerical increase in

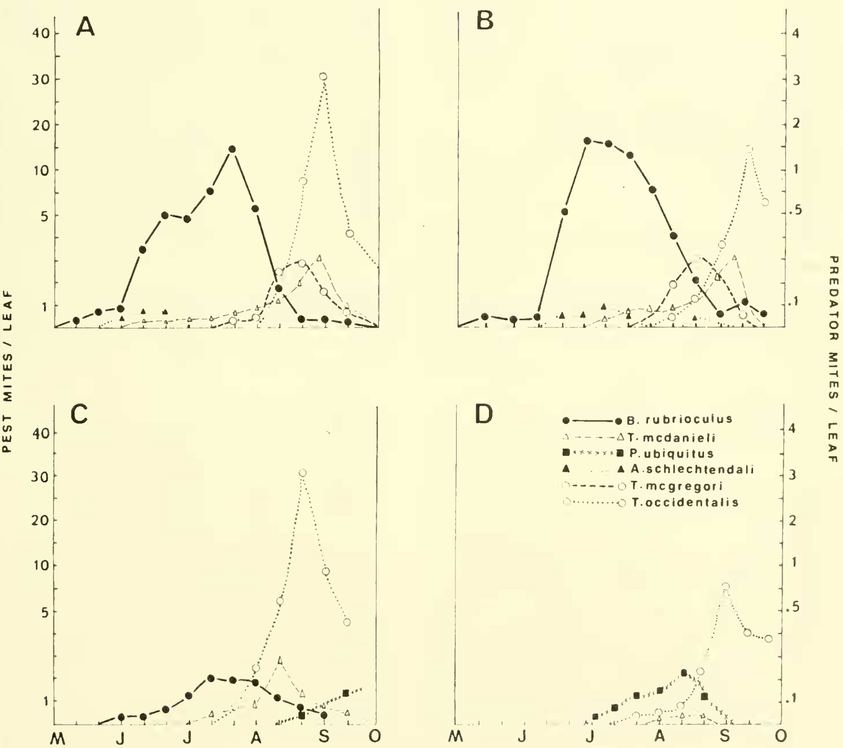

Fig. 2. Densities of plant-feeding and predaceous mites in four apple orchards unsprayed for 3-5 years at Oak Glen, California, during 1969 (A, B, and C) and 1970 (D): represents pooled values for 5 trees/orchard.

the predator populations, as *T. occidentalis* were frequently observed feeding on the tydeids.

In Figure 2D, *P. ubiquitus* populations attained 2.6/leaf and were the major prey supporting the populations of *T. occidentalis*, which increased to 0.8/leaf on 19 September. In this orchard, *Tet. mcdanieli-E. uncatus* populations did not exceed 0.3/leaf during the entire season and virtually no *B. rubrioculus* were observed.

Commercially Managed Orchards.— Figures 3A and 3B illustrate the population densities of *Tet. mcdanieli* throughout the summers of 1969 and 1970, in a sprayed orchard without any phytoseiid mites. *Tetranychus mcdanieli* exceeded 100/leaf in total orchard samples and, on occasion, exceeded 1,000 mites on individual leaves. If miticide sprays were not applied, intraspecific competition for food finally limited their increases, but only after severe damage to the apple foliage had been sustained.

During the summers of 1968 and 1969, over 200 samples (50 leaf spurs/sample) were taken from 19 other sprayed apple orchards. Less than 50 phytoseiid mites were collected from the foliage of apple trees at these sites, approximately equal numbers of *T. mcgregori* and *T. occidentalis*. Most of these predators were taken from peripheral trees which were near native, unsprayed vegetation. Predators were encountered only late in the growing season after pesticide residues were dissipated.

Although the selection of sites and the presentation of data in Figures 1-3 oversimplify the ecological differences between sprayed and unsprayed orchards at Oak Glen, California, the following species assessments were concluded from these data:

Bryobia rubrioculus was collected only in unsprayed orchards and was most abundant during the early summer. *Aculus schlechtendali* occurred at low levels in unsprayed plantings and varied greatly among locations from year to year. It was also observed at low densities in commercial orchards. Unsprayed orchards were never observed where *A. schlechtendali* occurred without *B. rubrioculus*, although some orchards supported *B. rubrioculus* only. *Tetranychus mcdanieli* was found most commonly in sprayed apple orchards in late summer when populations attained extremely high densities and caused serious damage to apple foliage in the absence of sufficient phytoseiid mites or adequate chemical control. This species and low densities of *E. uncatus* were also found in unsprayed trees where the tydeid mite, *P. ubiquitus*, was sometimes observed.

Typhlodromus mcgregori was always found in unsprayed orchards where *B. rubr-*

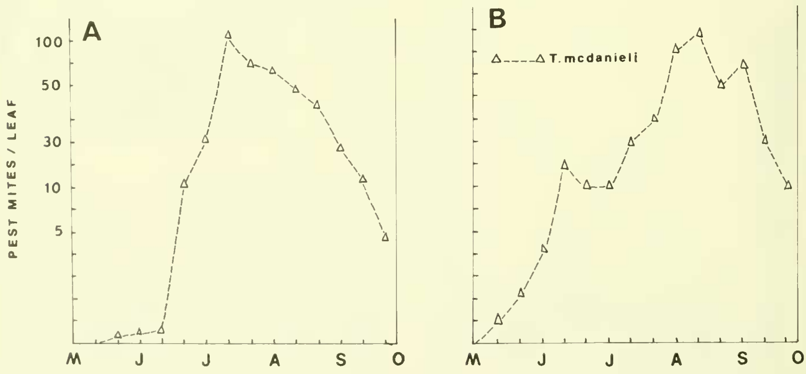

Fig. 3. Densities of *Tetranychus mcdanieli* in a sprayed commercial apple orchard at Oak Glen, California, during 1969 (A) and 1970 (B); represents pooled values for 5 trees.

ioculus occurred. The predators appeared to prey on this species, but they did not suppress its densities significantly. When *A. schlechtendali* was present with *B. rubrioculus*, *T. mcgregori* rapidly increased in response to the rust mites and seemed to suppress *B. rubrioculus* populations to a greater extent than when rust mites were absent. With the exception noted above, *T. occidentalis* was collected almost exclusively from unsprayed orchards where it was most closely associated with population complexes of *Tet. mcdanieli*, and *E. uncatus*, which were effectively maintained at low levels by the predator. *Pronematus ubiquitus* also appeared to be an adequate alternate host for *T. occidentalis* in several unsprayed orchards. Although Hoyt (1969) and Burrell and McCormick (1964) reported *A. schlechtendali* as a favorable prey species for *T. occidentalis*, the predator was never found in orchards at Oak Glen where only rust mites or *B. rubrioculus* were present. Only in one case in Utah was *T. occidentalis* found associated with *B. rubrioculus* and *A. schlechtendali*, and it was in a mixed block of apples, plums, and peaches along with high populations of rust mites and *Eotetranychus carpini borealis* Pritchard and Baker. We concluded from these data, as did Burrell and McCormick (1964), that *B. rubrioculus* probably is not an acceptable prey for *T. occidentalis*.

These observations and conclusions in relation to the bionomics of these species follow closely with those of Croft and Jorgensen (1969) and Duke et al. (1970), who reported the relationship of *T. mcgregori* in close association with *B. rubrioculus* in unsprayed apple orchards in Utah; and yet *T. mcgregori* did not exert any significant control of the prey. The association of *T. occidentalis* with *Tet. mcdanieli* and/or *E. uncatus* or closely related species was reported earlier by Hoyt (1969) for *T. occidentalis-Tet. mcdanieli*, Schuster and Pritchard (1963) for *T. occidentalis-Tet. pacificus* McGregor or *Eotetranychus willamettei* (McGregor), and Flaherty (1967) for *T. occidentalis-T. pacificus* or *E. williamettei*. In no instance, has *T. occidentalis* been reported as a predator of *B. rubrioculus*, yet this predator occurs in many geographical regions where *B. rubrioculus* is found.

One additional result which provides insight into the role of *T. mcgregori* as a predator of orchard pests relates to its relatively high oviposition rate/female/day when feeding on each of the three eriophyids: *A. schlechtendali* = 2.0 ± 0.2, *A. coronutus* = 1.9 ± 0.3, and *E. pyri* = 2.0 ± 0.1. The greatest average egg production observed for a 24-hour period was 2.3, which probably is close to the maximum for this species. Mean developmental time (egg-egg) for four replications of 10 *T. mcgregori*/replication feeding on *A. schlechtendali* were 8.5, 8.7, 8.0, and 8.5 days for an overall mean of 8.42 ± 0.3 hrs.

THE ROLE OF TYPHLODROMUS MCGREGORI: A REEVALUATION

Typhlodromus mcgregori occurs throughout North America north of Mexico and has been collected from several native plants in addition to walnut, grape, fig, apple, and citrus (Schuster and Pritchard 1963, Duke et al. 1970). Reported prey for this pedator includes *Aegyptobia nothus* P. and B., *Tet. pacificus*, *Eoteteranychus boudreauxi* P. and B., *Eriophyes vites* Pgst., *E. williamettei* and *B. rubrioculus* (Poe and Enns 1969, Schuster and Pritchard 1963, Duke et al. 1970).

Croft and Jorgensen (1969) studied the life history of *T. mcgregori* while it fed on *B. rubrioculus*, *P. ulmi* and *T. urticae* and observed that it preferred *B. rubrioculus* as compared to *P. ulmi* and *T. urticae*. They concluded that *T. mcgregori* did not assist substantially in controlling the latter two pests which occurred primarily in sprayed apple orchards in Utah. Even when feeding on *B. rubrioculus*, which *T. mcgregori* seemed most closely associated with in unsprayed orchards, the rate of development and oviposition rates were considerably lower than reported values for most other phytoseiid species which are efficient predators of tetranychid mites (McMurtry et al. 1970).

Duke et al. (1970) examined the distribution of *T. mcgregori*: (1) among apple orchards in Utah, (2) within apple orchards,

(3) within apple trees, and (4) upon apple leaves. They also reported the searching behavior of *T. mcgregori* on apple leaves. Predators were found principally in unsprayed orchards, aggregated within orchards, uniformly distributed within trees but nonuniformly upon leaves, and they searched leaves in a restrictive manner. In all cases, the predator distribution and searching behavior failed to closely correspond with movements and distributions of *B. rubrioculus*.

Nelson and Jorgensen (1968) further studied the dispersal and distributional associations between *T. mcgregori* and *B. rubrioculus* and found little or no correlation between predators and prey on spurs and leaves during the entire year or over a single 24-hour period. *Bryobia rubrioculus* was extremely mobile and present over a greater portion of the apple tree than was *T. mcgregori*.

To summarize, Jorgensen and co-workers listed three factors which contributed to the observed inability of *T. mcgregori* to appreciably affect or control populations of *B. rubrioculus* in the field: (1) *T. mcgregori* was limited in its reproductive and destructive ability when compared to the reproductive potential of *B. rubrioculus* (Croft and Jorgensen 1970); (2) *T. mcgregori* had limited potential for controlling *B. rubrioculus* because of differences in respective distributions in orchards, trees, and leaves and the predators' restricted searching behavior (Duke et al. 1970); and (3) *T. mcgregori* had dissimilar dispersal habits and spring distributions as compared to *B. rubrioculus*, which was more active and present over a greater portion of foliage and woody areas of apple trees (Nelson and Jorgensen 1968).

Considering the three factors suggested by Jorgensen and co-workers and in light of the data presented herein, we can now reevaluate the role of *T. mcgregori* as a predator of phytophagous mites in Utah and southern California apple orchards. We agree with Huffaker et al. (1969), who suggested that the comparative measure of oviposition between hosts and predators is only one aspect of a species rate of increase (r), and that r is only one component to the total predator response to its prey. Functional and numerical responses, and the subtractive effects of predation, must be considered in measuring the net effect of predation on a prey population. We do not consider the reduced oviposition rate of *T. mcgregori* when feeding on *B. rubrioculus* to represent a major limiting factor to its ability to control the latter, but rather its inefficiency is more likely explained by other means.

Both Duke et al. (1970) and Nelson and Jorgensen (1968) pointed out that the spatial occurrence (distribution and dispersal movement) of *T. mcgregori* was only loosely associated with that of *B. rubrioculus*. If the predator-prey association was primary, this incongruity would be an important factor in limiting effective predation. We now question the assumption of primary association altogether.

It is apparent that neither the Utah nor southern California strain of *T. mcgregori* are primarily adapted to the spider mites (e.g. *P. ulmi*, *Tet. urticae*, *Tet. mcdanieli*) which most commonly occur in sprayed orchards. Feeding studies by Croft and Jorgensen (1969) suggested a lack of association with *P. ulmi* or *Tet. urticae* for the Utah strain and population studies in both areas indicated little or no association with *Tet. mcdanieli*. Also, colonies of *T. mcgregori* do poorly in the laboratory when reared on *Tet. pacificus* (B. A. Croft, unpublished data).

The relationship between *T. mcgregori* and *B. rubrioculus* is unclear, since both species were consistently found together in unsprayed orchards during the growing season. It is not known whether this is a primary association and *B. rubrioculus* is the preferred prey, or a secondary association allowing for the maintenance of *T. mcgregori* populations at low levels, or an association which develops after predators respond to other species (e.g., *A. schlechtendali*). The latter question seems most likely considering the reproductive rates reported herein for *T. mcgregori* when feeding on three rust mite species, including *A. schlechtendali*. Croft and Jorgensen (1969) reported 11.5 days (egg-egg) for developmental time and 1.2 eggs/day/female for *T. mcgregori* when feeding on *B. rubrioculus.* When preying on *A. schlechtendali*, these predators developed about three days faster and oviposited *ca* 0.8 eggs/female more per day. Eriophyid mites also have been reported as equal to or more favorable prey than tetranychids for several other phytoseiid species (Chant 1959, Hoyt 1969, Burrell and McCormick 1964).

Huffaker et al. (1969) generalized that "some species of such mites (e.g. *Bryobia arborea)* seem highly immune to predators that are so efficient against certain species of *Panonychus* and *Tetranychus*. . . ." (*Bryobia arborea* Morgan and Anderson = *B. rubrioculus.)* Few workers have reported efficient predation between any phytoseiid species and *B. rubrioculus* (McMurtry et al. 1970), and reports of poor predation and reproduction are common (Herbert 1959, Burrell and McCormick 1964). Several features of the morphology, behavior, and biology of *B. rubrioculus* may account for this immunity, including the large size of the adult mites (McMurtry et al. 1970) and their highly mobile behavior, particularly the adults which spend a large portion of their time on the woody parts of the plant, where they lay many eggs (Nelson and Jorgensen 1968).

Typhlodromus mcgregori was seldom found on sprayed plantings in either study area, although *A. schlechtendali* occurred in both unsprayed and commercial orchards. Another contributing factor to its absence from sprayed orchards and its replacement in many areas other than Oak Glen by the predator, *T. occidentalis*, may be related to a differential susceptibility of these two predators to pesticides. *T. occidentalis* has developed resistance to many pesticides that are commonly applied for apple pest control in most fruit-growing areas where pesticides have been widely used (Croft and Jeppson 1970). Croft (unpublished data) found a California strain of *T. mcgregori* to be highly susceptible to laboratory applications of 0.5 mg/ml sol. of technical azinphosmethyl (96 percent purity) when tested using the slide dip method. This pesticide is the most common insecticide applied in apple orchards of Utah or southern California, and its application undoubtedly contributes to the exclusion of *T. mcgregori* from sprayed orchards in both areas.

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